National Aeronautics and Space Administration

NASA Ames Sustainability Base

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Prediction of Adverse Events in Time Series Data Using ACCEPT (Adverse Condition and Critical Event Prediction Toolbox)

25-06-2014

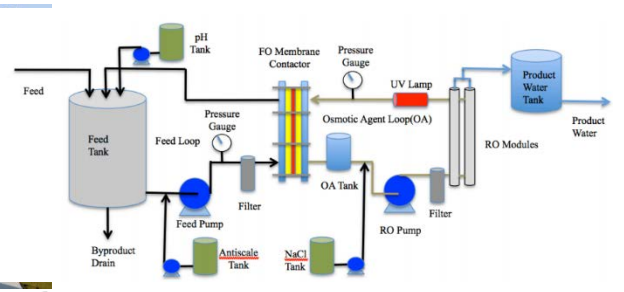
For Sustainability Base (N232), Intelligent Systems Division technologies are currently aimed at the following:

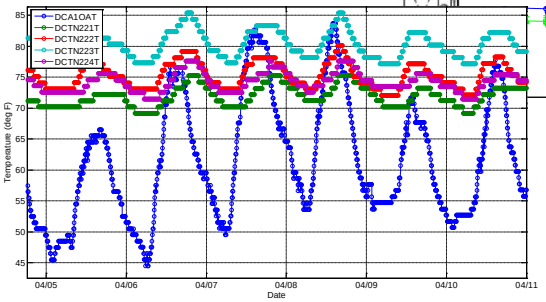
Research Objectives

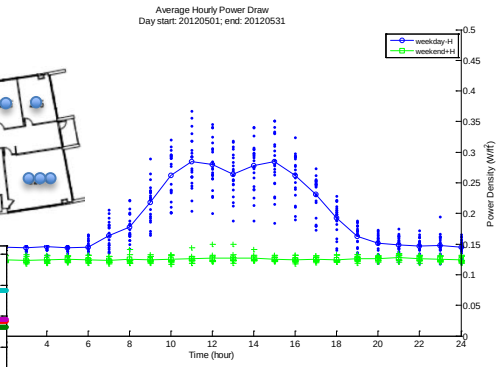
- Reduce energy use, water use, and greenhouse gas emissions
- Increase efficiency of operations and maintenance activities
- Mature TI research technologies and extend range of applicability to new domain
- Demonstration of TI technologies on dashboard (lobby display and/or URL)

Near-term TI Applications

- Diagnostic and prognostic modeling of WRS (Water Recycling System) for membrane replacement/cleaning
- WebIMS, Orca, etc., for detection of undesirable plug load usage and malfunctioning devices
- Project Haystack-based API development for semantic tagging of FMCS point names
- *ACCEPT (Adverse Condition and Critical Event Prediction Toolbox),* NuPIC (Numenta Platform for Intelligent Computing) *for CBM (condition-based maintenance) and advance prediction of critical FMCS alarms*







Potential TI Applications

- HyDE (Hybrid Diagnosis Engine) for diagnostic modeling of geothermal system
- Intelligent Solar Forecasting and Diagnostics for Photovoltaics
- MPC (Model Predictive Control) for heating/cooling and ventilation systems
- Wireless sensing and distributed control

ACCEPT (Adverse Condition and Critical Event Prediction Toolbox)

Provides Open, Special-Purpose Functionality

- Goal is to provide an ***open-source*** tool which can be used ***specifically for the prediction or forecasting of adverse events in time series data***
- Provides a single, unifying framework in which to compare a variety of combinations of algorithmic approaches addressing this problem
- Provides a platform whose intention is to act as a catalyst in advancing the state of the art in technologies related to this problem
- MSET (Multivariate State Estimation Technique) and variations thereof is the current defacto industry gold standard for these technologies
    - Originally developed at Argonne National Laboratories
    - Has since been adapted for myriad applications spanning a broad range of disciplines

Current Datasets

- FOQA data
    - Dataset posted on DaSHlink: https://c3.nasa.gov/dashlink/projects/85/
    - Internal dataset
- Sustainability Base data (summer interns hard at work on this !)

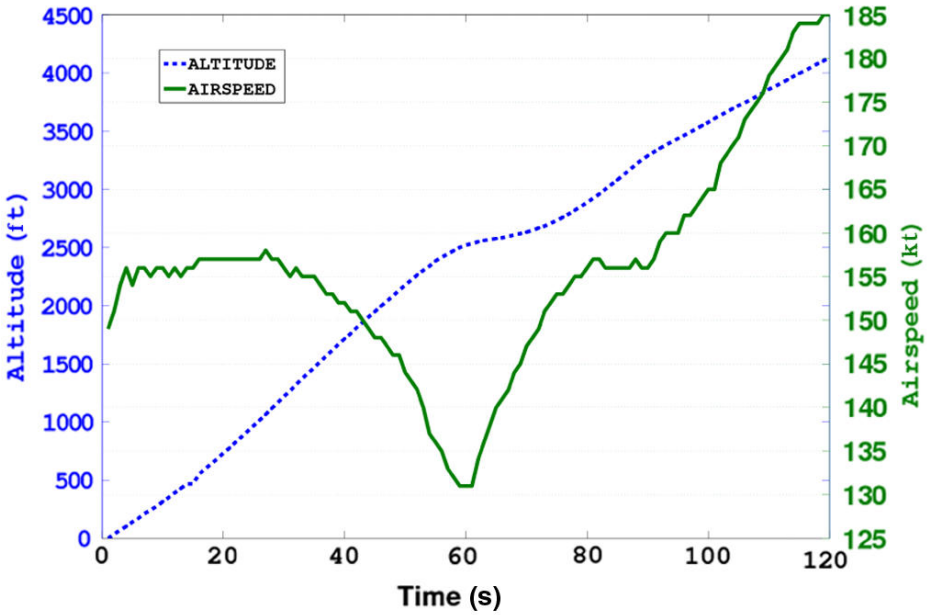
Current, Potential & Future Applications

- *Advance prediction of aviation safety incidents, aircraft equipment failures*
- *Advance prediction of critical FMCS alarms in buildings*
- CBM (condition-based maintenance) for aircraft fleets (SmartSignal)
- Space propulsion (SSME data analysis SureSense® by EMI)
- Nuclear (MSET, PEM toolbox for Matlab)
- Disk drive servo failures (Western Digital)

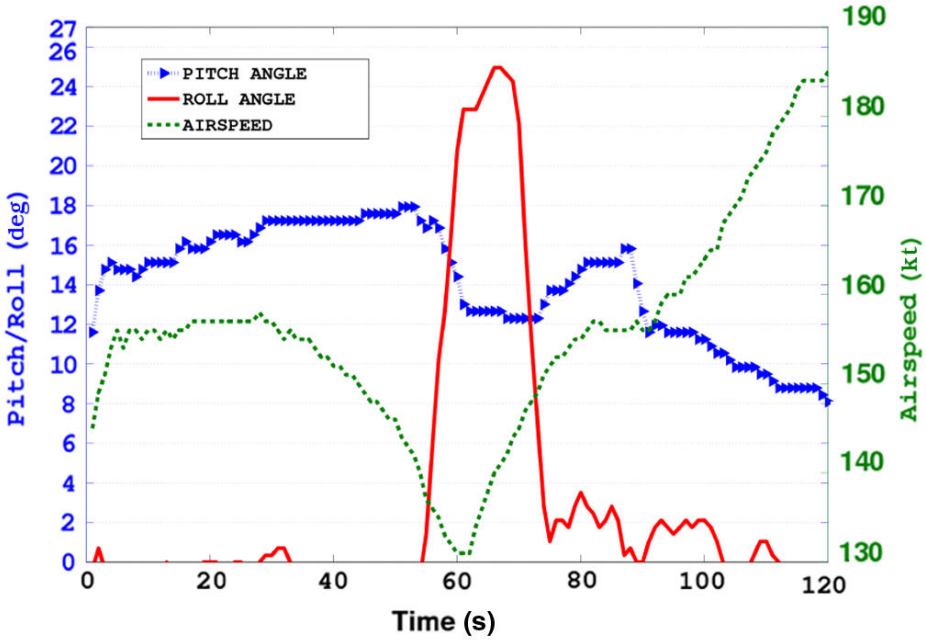
ACCEPT (Adverse Condition and Critical Event Prediction Toolbox)

Current Use Cases/Scenarios for ACCEPT

- IFESD (In-Flight Engine Shutdown) prediction problem based upon dataset posted on DaSHlink: https://c3.nasa.gov/dashlink/projects/85/
- Loss of Airspeed during ascent which comes nearly within 10 kts of stall speed during execution of a roll maneuver



a) Drop in airspeed with the corresponding altitude at which it occurred

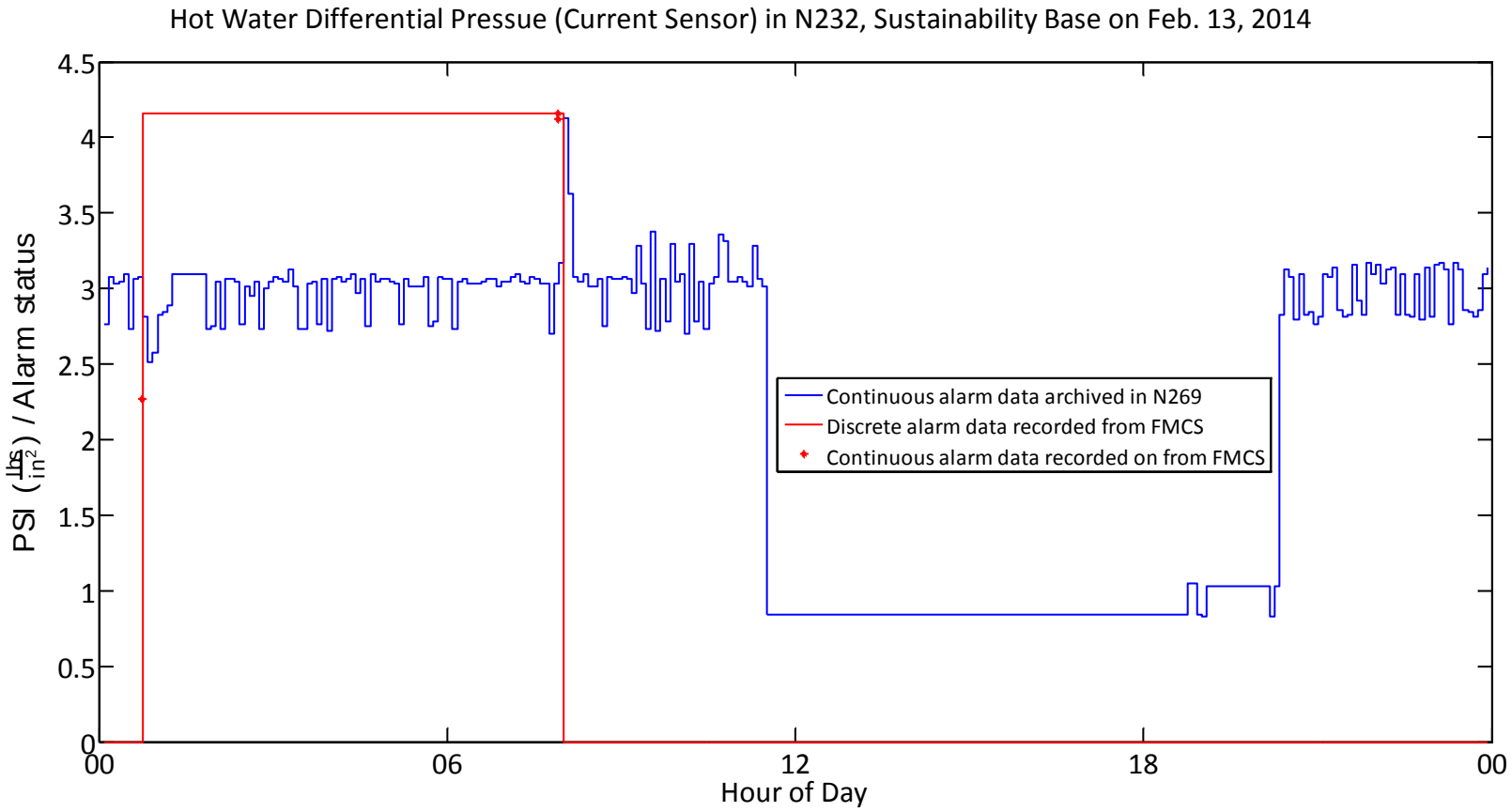


b) Airspeed recovery as the pilot performed a roll maneuver and simultaneously began correcting the pitch to begin increasing airspeed

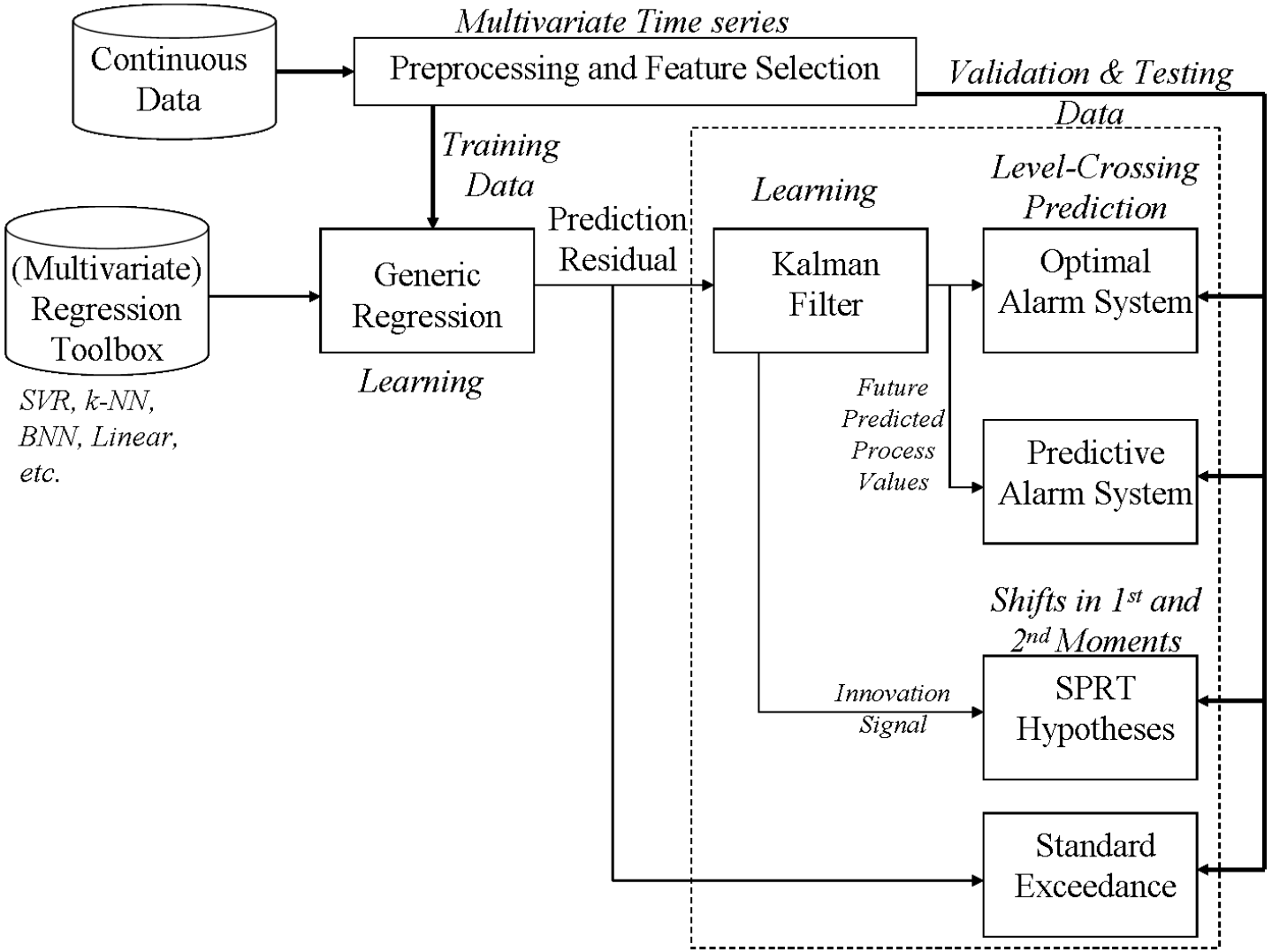
ACCEPT (Adverse Condition and Critical Event Prediction Toolbox)

Current Use Cases/Scenarios for ACCEPT

- Advance prediction of critical FMCS alarms in buildings



ACCEPT (Adverse Condition and Critical Event Prediction Toolbox) Framework



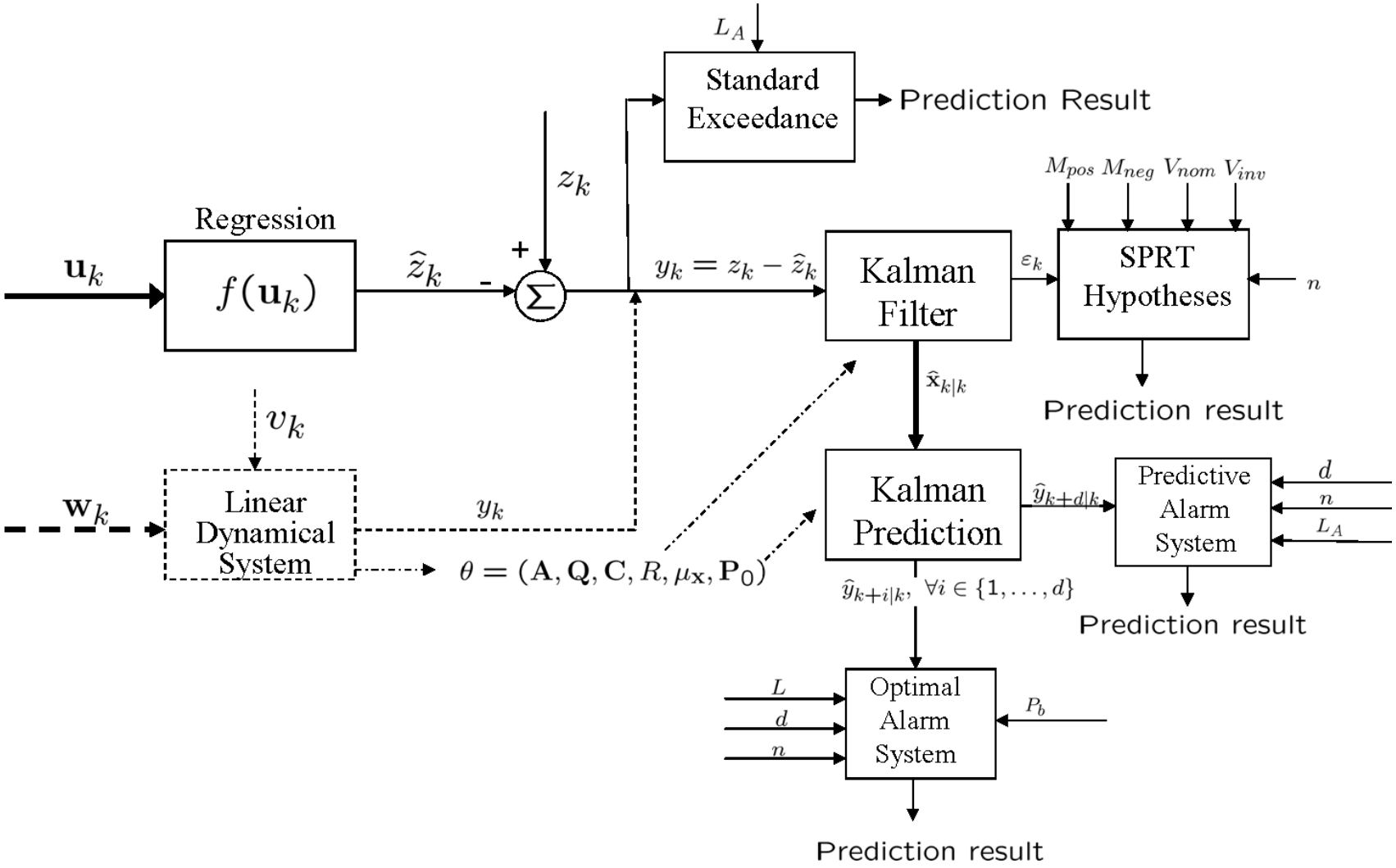
MATLAB Toolboxes Required for Full Functionality

- Statistics Toolbox (MATLAB)
  - Basic requirement
- Parallel Computing Toolbox (MATLAB)
  - Required for running distributed jobs on cluster (if available) to reduce processing time
- MATLAB Compiler (MATLAB)
  - Required for running distributed jobs on cluster (if available) to reduce processing time, if Parallel Computing Toolbox is not available
- Global Optimization Toolbox (MATLAB)
  - Required to run global optimization routines in support of regression and/or detection modules
- Control Systems Toolbox (MATLAB)
  - Required for any detection method using an LDS
- Neural Network Toolbox (MATLAB)
  - Required for testing BNN (Bagged neural networks) as one the regression methods

Third Party Toolboxes Required for Full Functionality

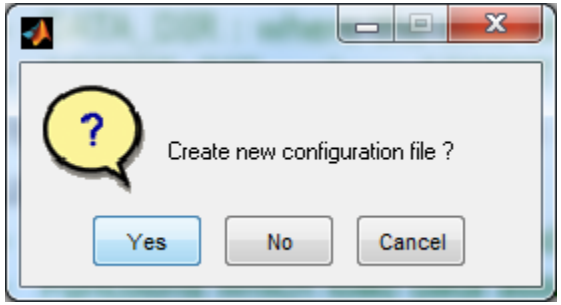
- BatchBench
  - Basic requirement
- Netlab
  - Basic requirement
- Regression Wrapper Code (to possible include calls from Virtual Sensors toolbox)
  - Basic requirement
- KPMstats and KPMtools Toolboxes (Kevin Murphy, MIT/GPL)
  - Basic requirement
- SMO code for SVM routine ?
  - Required for running SVM as one of the regression methods
- Kalman Filter Toolbox (Kevin Murphy, MIT/GPL)
  - Required for any detection method using an LDS
- LDS stability constraint toolbox (Siddiqi et al., no formal license other than a requirement to acknowledge researchers by citation of corresponding paper)
  - Required for any detection method using an LDS
- N4SID Toolbox (Overschee & DeMoor, International, no formal license)
  - Required for any detection method using an LDS
- Optimal Alarm Toolbox (Rodney Martin, NOSA)
  - Required for running Optimal Alarm System as one of the detection methods
- ASOS Toolbox (James Martens, Apache 2.0)
  - Option for any detection method using an LDS
- CAMCOS LDS Initialization script (SJSU released to NASA)
  - Option for any detection method using an LDS
- CVX toolbox (Michael Grant & Stephen Boyd, GNU General Public License 2.0)
  - Option for any detection method using an LDS
- B. Matthews' toolbox to set up distributed computing w/ Matlab compiler (Matthews, NF1679 invention disclosure submitted)
  - Option for distributed computing only (if a computing cluster is available)

ACCEPT (Adverse Condition and Critical Event Prediction Toolbox) Framework

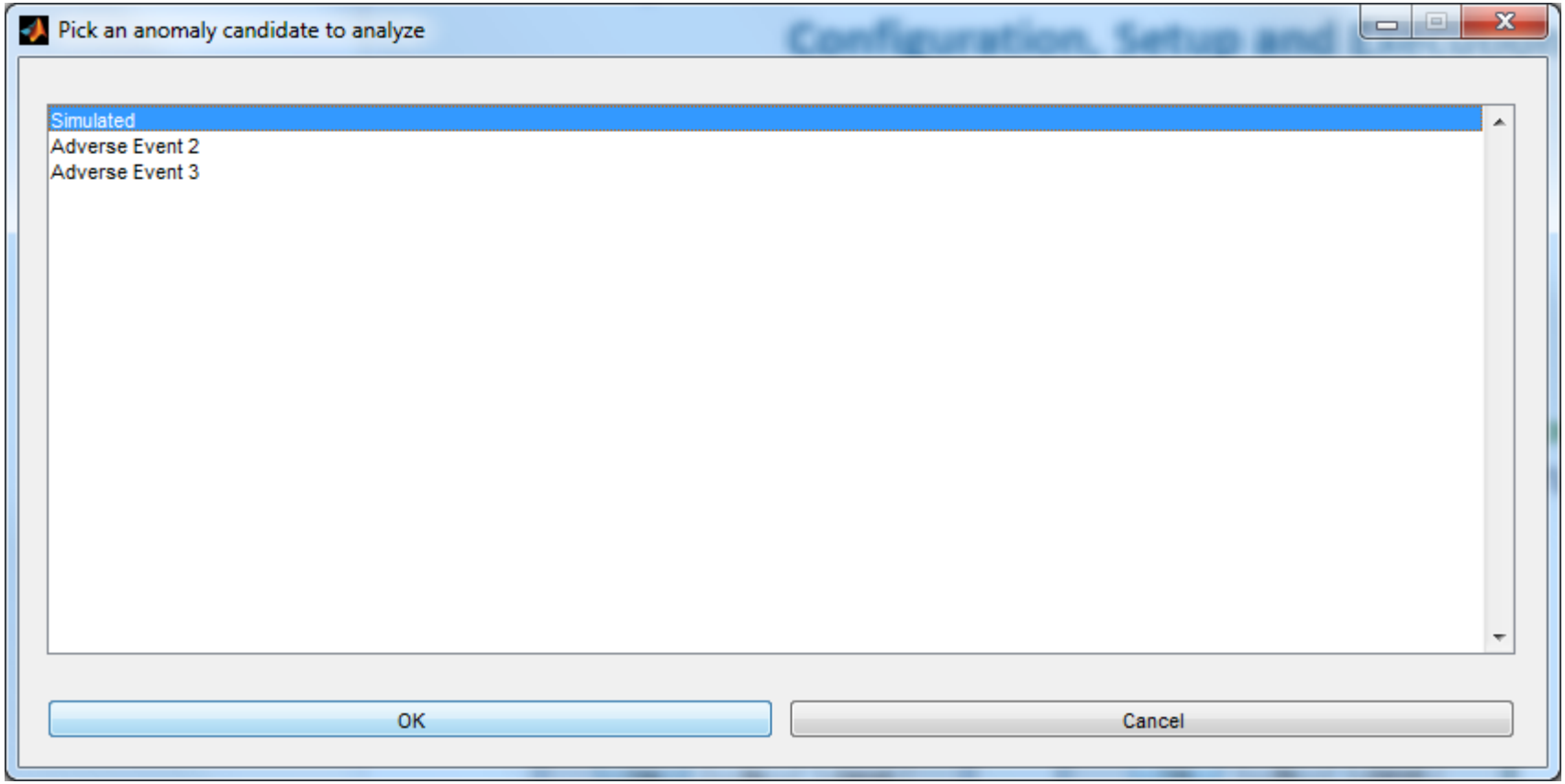


ACCEPT (Adverse Condition and Critical Event Prediction Toolbox) Configuration, Setup and Execution

- Environment variables to set
  - DATA_DIR : where the data sits
  - ACCEPT_DIR : where ACCEPT code sits
- Create parameter list (both input/response variables)
- Customized functions
  - Functions which create ground truth for adverse events
  - Functions which load data associated with specific use cases/scenarios
- Call to run ACCEPT or combine results from previous runs



ACCEPT (Adverse Condition and Critical Event Prediction Toolbox) Sample Screenshots



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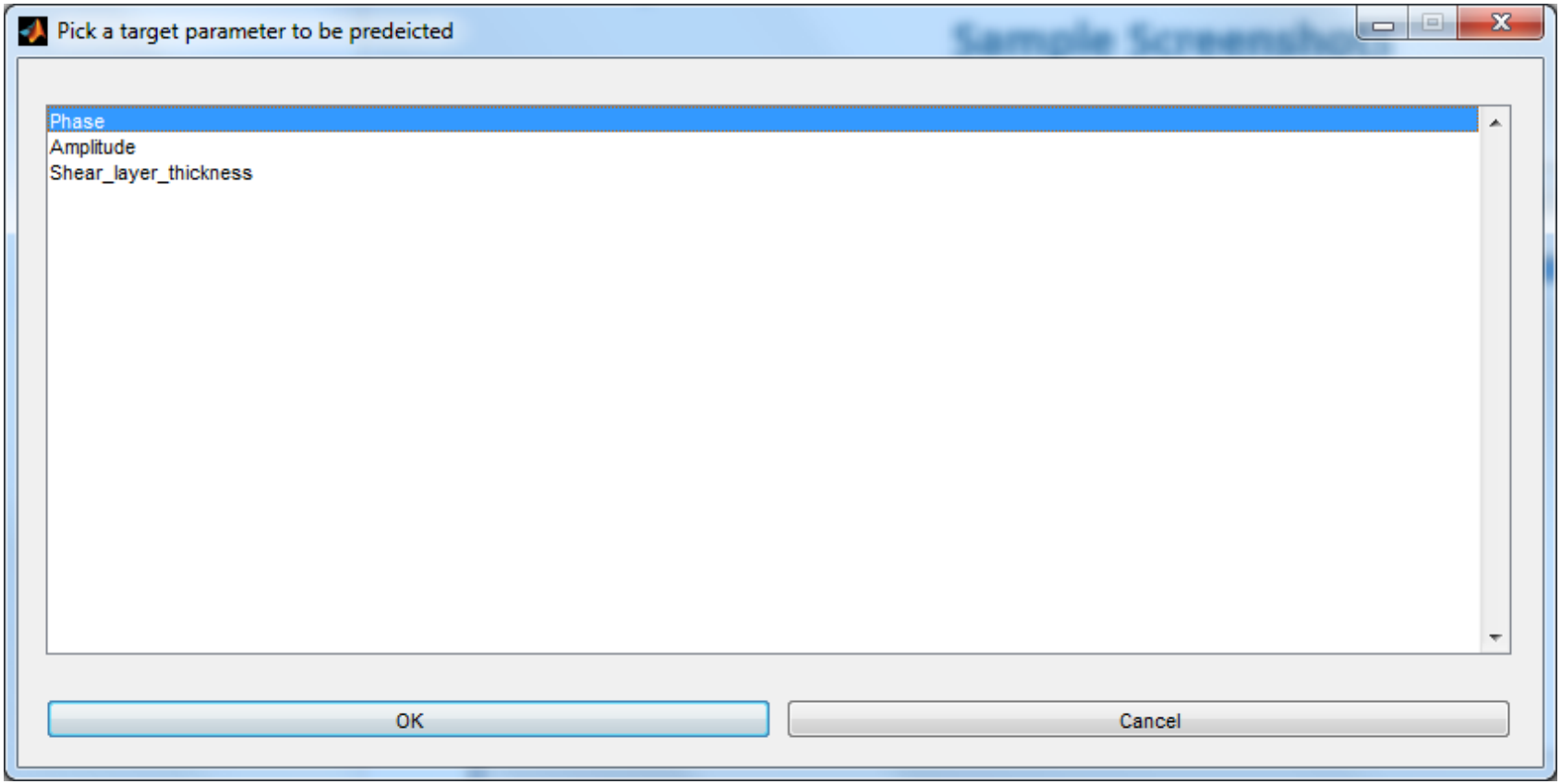

ACCEPT (Adverse Condition and Critical Event Prediction Toolbox) Results

Regression results...

	svr	knn	lin	quad	bnet
Global Optimum	2.8480	44	0.1556	1.1e-05	2
Optimized Values	0.2963	0.2708	0.3039	0.2978	0.2752

Missed detection results...

	svr	knn	lin	quad	bnet
Redline - Training	0.0000	0.1111	0.0000	0.0000	0.0000
Redline - Validation	0.0000	0.0833	0.0000	0.0000	0.0000
Predictive - Training	0.0000	0.1389	0.0000	0.0000	0.0000
Predictive - Validation	0.0556	0.1111	0.0000	0.0000	0.0000
Optimal - Training	0.0278	0.1389	0.0000	0.0000	0.0000
Optimal - Validation	0.0278	0.1111	0.0000	0.0000	0.0000
SPRT	0.2778	0.3056	0.0000	0.1389	0.0833

False alarm results...

	svr	knn	lin	quad	bnet
Redline - Training	0.3237	0.1367	0.3165	0.3237	0.3094
Redline - Validation	0.3165	0.2518	0.1655	0.1439	0.3597
Predictive - Training	0.4532	0.1439	0.2662	0.4317	0.3022
Predictive - Validation	0.2806	0.3309	0.1727	0.1439	0.3022
Optimal - Training	0.1942	0.0504	0.3813	0.2662	0.1727
Optimal - Validation	0.3597	0.3237	0.2014	0.2302	0.2950
SPRT	0.0000	0.0000	0.2806	0.0000	0.1151

Detection time results...

	svr	knn	lin	quad	bnet
Redline - Training	5.0000	9.0000	1.0000	5.0000	1.0000
Redline - Validation	5.0000	5.0000	1.0000	5.0000	1.0000
Predictive - Training	4.0000	18.000	1.0000	1.0000	5.0000
Predictive - Validation	1.0000	10.000	2.0000	19.000	5.0000
Optimal - Training	1.0000	0.0000	1.0000	5.0000	5.0000
Optimal - Validation	4.0000	10.000	2.0000	5.0000	5.0000
SPRT	0.0000	0.0000	1.0000	0.0000	5.0000

ACCEPT (Adverse Condition and Critical Event Prediction Toolbox) Next Steps

- Augment Regression Toolbox
  - Create subcategories of regression models
    - Generate a residual based upon prediction that is temporally invariant (current methods)
    - Generate a residual based upon prediction which rely on AR or ARMA-style modeling approaches (e.g. NuPIC)
    - Generate a residual based upon predicting the next time step (e.g. NuPIC)
  - Add ELM (Extreme learning machines)
  - Add variants of deep learning
    - DBM (Deep Boltzmann Machines)
    - DNN (Deep Neural Networks)
    - CNN (Convolutional Neural Networks)
    - RNN (Recurrent Neural Networks - AR/ARMA-style)
    - LSTM (Long Term Short Memory Network - AR/ARMA-style)
- Augment Detection Toolbox
  - GLR
  - CUSUM
  - etc.